IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Application No.: 10/758,816

Filing Date: January 16, 2004

Applicants: Michael W. Murphy et al.

Group Art Unit: 1795

Examiner: Cynthia K. Lee

Title: ULTRA SHORT HIGH PRESSURE GRADIENT FLOW PATH FLOW FIELD

Attorney Docket: 8540G-000233 (Client Ref. No. GP-303355)

Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

DECLARATION OF PRIOR INVENTION IN THE UNITED STATES TO OVERCOME A CITED PATENT PUBLICATION PURSUANT TO 37 C.F.R. § 1.131

Purpose of Declaration

1.   I am a co-inventor of the patent application identified above and co-inventor of the subject matter described and claimed therein, including the subject matter of pending Claims 1 - 9.

2.   I have been informed and understand that the U.S. Patent and Trademark Office has cited the Tsunoda reference (U.S. Patent No. 7,258,944), filed on June 27, 2003, against my pending application.

3. This declaration is being presented to establish conception and reduction to practice of my invention in the United States at a date prior to the June 27, 2003 filing date of the Tsunoda reference.

Facts and Documentary Evidence

4. My co-inventors and I invented the subject matter of our pending patent application before the effective date of the Tsunoda reference. Attention is respectfully drawn to the redacted General Motors Record of Invention (ROI), attached as Exhibit A (pages 1-20). The redacted portions of Exhibit A do not contradict any of the remaining information, but do not add any further relevant information. The ROI is signed on page 4 by my co-inventors and by myself. The redacted date next to our signatures is earlier than the June 27, 2003 effective date of the Tsunoda reference.

5. The attached ROI is evidence of conception and reduction to practice of the subject matter of Claims 1 - 9. As can be seen on page 5, number 11, by at least the date of submission of the ROI the invention had been tested and reduced to practice.

6. The attached ROI was received by the General Motors Legal Staff prior to June 27, 2003 and processed through its standard procedure for preparing and filing a patent application. At no time prior to the filing of our patent application was the invention abandoned, suppressed, or concealed.

7. Independent Claim 1 recites a fuel cell having a first planar manifold defined between a first gas-impermeable element and an active element. A plurality of spacers are disposed within the first planar manifold where each of the spacers and the first gas-impermeable element have an orifice formed therethrough. A second planar manifold is defined between the first gas-impermeable element and a second gas-impermeable element, which is in a subjacent relationship with the first planar manifold. A flow path is established from the second planar manifold, through the orifice, across the active element, and back into the first planar manifold.

8.   Page 12 of the ROI describes the subject matter claimed in independent Claim 1. In particular, the ROI describes two physically separable manifolds connected to each other through an active element. Gases flow through the fuel cell in the following way:

a)   from a first manifold to a second manifold by passing through the tunnels connecting the first manifold to the active element;

b)   then flowing radially over the top of the disc (through the active element); and

c)   finally spilling into the spaces between the discs that make up the second manifold.

9.   Pages 12 - 20 of the ROI establish the remaining features of Claims 2 - 9. In particular, support for Claims 2, 3, and 6 can be found on page 12 of the ROI; support for Claims 4, 7, and 8 can be found on page 14 of the ROI; support for Claim 5 can be found on pages 12 and 19 (Figure 3C); and support for Claim 9 can be found on page 20 (Figure 3D).

10.   The ROI has been redacted to remove personal information, potential trade secrets, and other information not relevant to establishing a date of invention earlier than the Tsunoda reference. The non-redacted portions show that my co-inventors and I invented the subject matter of the claims prior to the effective date of the Tsunoda reference.

11.   The information provided under Inventor #4 on page 6 of the ROI has been redacted due to a lack of inventive contribution to the claimed invention. As can be seen from page 4, only those providing inventive contribution have been included in the signatory portion of the ROI.

<u>Declaration</u>

12. Under penalty of perjury, I swear that all statements made herein on personal knowledge are true and all statements made on information and belief are believed to be true. I have been warned that willful false statements and the like are punishable by fine, imprisonment, or both under 18 U.S.C. § 1001, and that such willful false statements can adversely effect the validity of the application or any patent issued thereon.

Michael W. Murphy (signature)   Date: ___May 15, 2009___

Michael W. Murphy

_____   Date: _____

Wenbin Gu

_____   Date: _____

Lewis J. DiPietro

14490765.1

Declaration

12.   Under penalty of perjury, I swear that all statements made herein on personal knowledge are true and all statements made on information and belief are believed to be true. I have been warned that willful false statements and the like are punishable by fine, imprisonment, or both under 18 U.S.C. § 1001, and that such willful false statements can adversely effect the validity of the application or any patent issued thereon.

_____   Date: _____
Michael W. Murphy

_____   Date: ___5/19/2009___
Wenbin Gu

_____   Date: ___5/19/2009___
Lewis J. DiPietro

14490765.1

EXHIBIT A

37 C.F.R. §1.131 Declarations of:
Michael W. Murphy, Wenbin Gu, and Lewis J. DiPietro

U.S.S.N. 10/758,816
"Ultra Short High Pressure Gradient Flow Path Flow Field"

GM **GENERAL MOTORS CORPORATION**

File No. _GP-393-355_

RECORD OF INVENTION

This Record of Invention must be completed with sufficient detail so that your invention can be understood and evaluated by both your engineering management and by a GM Legal Staff patent attorney. Novelty and competitive significance of your invention will be evaluated based on the information you provide.

Invention Title: Ultra-short, high pressure gradient flow path flow field

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Inventor #1

Name: Michael _____ W _____ Murphy _____ Citizen of: USA
   First Name   Middle Initial   Last Name

Social Security No. ▓▓▓▓▓▓   GM Employee: ☒ Yes ☐ No   ☒ Salary ☐ Hourly ☐ Contract

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                                        Centrex Number   (Area Code) + Number

GM Address: 10 Carriage St., Honeoye Falls, NY 14472   Mail Code: _____   FAX Number: (8)-624-6680
                                                                                      Centrex Number

Non-GM Employer: _____   Phone No. _____
                                      (Area Code) + Number

Non-GM Employer Address: _____ _____ _____
   Street   City and State   Zip Code

Inventor #2*

Name: Wenbin _____ _____ Gu _____ Citizen of: USA
   First Name   Middle Initial   Last Name

Social Security No. ▓▓▓▓▓▓   GM Employee: ☒ Yes ☐ No   ☒ Salary ☐ Hourly ☐ Contract

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                                        Centrex Number   (Area Code) + Number

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                                                                                      Centrex Number

Non-GM Employer: _____   ~~Phone No.~~ _____

RECEIVED
GENERAL MOTORS CORPORATION

Non-GM Employer Address: _____ _____ ▓▓▓▓
   Street   City and State

* If there are more than two (2) inventors for this invention use the template at the end of this form.

▓▓▓▓   File Number: _____

LEGAL STAFF

1 of 6

Answer questions 1 - 8, completing all of them to the best of your knowledge.

1. This invention was first thought of on: █████████ _____

2. This invention has been or is expected to be disclosed outside GM on: _____

3. This invention has been used or is committed to be used in production on: _____

4. This invention has been offered for sale outside GM on: _____

5. Was this invention made while working on a Government Contract?   ☐ Yes ☒ No

   If yes, identify the government Contract No. _____

6. Identify the product or process in which the invention is incorporated: <u>PEM fuel cell bipolar plate</u>

7. List all individuals who can provide information about the making of the invention. .This list may include individuals who made the first sketch, description, or tests and individuals who are familiar with the facts relating to the making of the invention.
   Michael Murphy, GM
   Wenbin Gu, GM
   Lew diPietro, GM
   Kerry Kearney, Tech-Etch, Inc.

8. Each inventor has a legal duty to disclose all information known that is material to patentability of this invention. Such information includes the relevant prior art, which may be in the form of current or past products, equipment, processes, materials, patents, publications, advertisements, displays, and unpublished developments and proposals—whether originated by you, others in GM, competitors, suppliers, customers or others. Such information also includes disclosure of this invention outside GM, sales and offers of products using this invention, use of this invention in production and disputes about who should be considered as an inventor of this invention. To comply with the duty to disclose, list here and attach a copy of all such information, to the extent known.
   This invention was built by Tech-Etch according to GM's design requirements

Answer question 9 thoroughly.

9. Describe the invention in sufficient detail so that its nature, operation and usefulness can be understood. (Attach drawings, diagrams and further description, when necessary. Additional guidelines are listed below.)

see attached

Mechanical and Electrical Devices: Include illustrations assigning reference numbers to the main elements and refer to the reference numbers in a description that explains how the main elements are connected or related and how they operate.

Electrical Circuits and Controls: Include circuit diagrams and a functional description.

Computer Software and Manufacturing or Business Processes: Include a flowchart or other step-by step overview.

Chemical Inventions: Identify all essential materials used, and alternatives therefor, in chemical terms – not tradenames. Identify and quantify all significant variables (e.g. temperature, pressure, concentration, pH etc.) of the process or material specifying operating ranges and the preferred example. Discuss the significance of each variable. Provide a recipe for at least one working example of the invention.

I hereby assign this invention to General Motors Corporation
and authorize General Motors Corporation to file an application on my behalf.

Michael W. Mu.g   Michael Murphy   ███████
INVENTOR – SIGNATURE   (ALSO, PRINT NAME)   DATE

Wenbin Gu   Wenbin Gu   ███████
INVENTOR – SIGNATURE   (ALSO, PRINT NAME)   DATE

Lewis J. DiPietro   LEWIS J. DiPieTRo   ███████
INVENTOR – SIGNATURE   (ALSO, PRINT NAME)   DATE

This invention was reviewed and understood by me:

Thomas A. Trabold   Thomas A. Trabold   ███████
1st WITNESS – SIGNATURE   (ALSO PRINT NAME)   DATE

_____   _____   _____
2nd WITNESS – SIGNATURE   (ALSO, PRINT NAME)   DATE

Answer the following questions if helpful in describing this Invention

10. What benefits will be realized by using this invention?

Improved water management
Stable gas flow
Prevention of low performing cells
Lower overall pressure drop
Improved gas flow distribution
Improved control of gas stoich and humidity delivery
Lower mass transport losses

11. What is the state of development of this invention?
Computer model has been designed which reinforces the design's intended benefits. Sample flow field has been constructed, demonstrating that the design can be built. ███████████████████████████████████

12. To the extent known, what alternatives exist for accomplishing substantially the same result as this invention?
No alternatives are known that can satisfy the range of requirements that this design is able to satisfy simultaneously, with the minimum of trade-offs.

13. Describe the background of the invention. This description may include the state of the prior art and may identify deficiencies in the prior art that are overcome by this invention.
Long channel flow fields can be considered prior art. The deficiency that this design overcomes is that it has the ability to satisfy the competing requirements of good water removal, low overall pressure drop, high area coverage, stable gas flow, and even gas flow distribution all at the same time.

Inventor # 3

Name: Lewis _____   J _____   DiPietro _____   Citizen of: USA _____
              First Name   Middle Initial   Last Name

Social Security No. ████████_____   GM Employee: ☒ Yes ☐ No   ☒ Salary ☐ Hourly ☐ Contract

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                                          Centrex Number   (Area Code) + Number

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                                                        Centrex Number

Non-GM Employer: _____   Phone No. _____
                                                          (Area Code) + Number

Non-GM Employer Address: _____   _____   _____
                                Street   City and State   Zip Code

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Inventor # 4

██
      First Name   Middle Initial   Last Name

██

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      Street   City and State   Zip Code

██
                              Centrex Number   (Area Code) + Number

██
                                            Centrex Number

██
                                            (Area Code) + Number

██
      Street   City and State   Zip Code

Concept for an ultra-short, high pressure gradient flow path flow field design

This document describes a flow field design concept for achieving stable gas flows in the presence of liquid water, as well as for heightening the oxygen partial pressure in the catalyst layer in order to raise cell performance.

Part A of this document defines the requirements of any flow field, shows the difficulty in satisfying all of these requirements simultaneously, and introduces a new design idea for getting around the problem of satisfying these simultaneously. The benefits of the idea, why it should work, limitations of the design, and some unintended benefits are also described. Part B describes a specific design for implementing this concept, as well as how this specific design can be used to establish convective, interdigitated-like flow in the DM in order to raise the PO2 at the catalyst layer.

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Page 8

REDACTED
Page 9

REDACTED
Page 10

Part B: A specific design for achieving stable flow, as well as for establishing convective flow in the DM

An actual design

From Part A it was concluded that the design aspects needing to be found in any flow field design that can satisfy all seven flow field requirements at once are:

1. High pressure gradient
2. Short flow path length
3. High number of parallel paths

Furthermore, it was also shown that in order for a design with these aspects to work successfully, the following additional aspects are needed to guarantee even flow distribution:

1. Near-zero pressure drop delivery and removal segments
2. Physically short, high pressure gradient active area segment

Combining these two lists, and translating them into a list of physical features, a flow field designed according to the above criteria will have the following physical features:

1. Open, easily-flowing gas delivery manifold
2. Open, easily flowing gas exhaust manifold
3. Many short, parallel flow connections between these manifolds containing a flow-interfering medium
4. A flow-interfering medium having a well-controlled permeability, as well as controllable dimensions for length and cross-sectional area

One design that contains all of these features is shown in Figure 3. In this design, two thin, parallel gas spaces are created that extend over the entire active area of a cell. In the gas space closest to the DM, there is an array of metal discs as tall as the gas space is high, and containing a hole in the center of each. The hole in each disc forms a tunnel that connects the gas space further from the DM to the DM layer itself. In the gas space further from the DM are smaller metal discs that electrically connect the bottom of the entire assembly to the discs in the top plenum. These discs complete the electrical connection from the bottom layer to the DM, making the entire assembly electrically conductive from top to bottom.

What this design creates is two open manifolds, physically separated from one another except by passages through the DM. Gas is able to flow from the bottom manifold to the top one by passing though any one of the tunnels that connect the bottom manifold to the DM, then by flowing radially over the top of the disc (through the DM), and finally spilling into the spaces between the discs that make up the top manifold. In this design, the DM itself serves as the flow-interfering medium.

The radius of the disc facing the DM establishes the length of a flow path. The number of discs establishes the number of parallel paths. The circumference of the disc at a given distance from its center, multiplied by the DM thickness, establishes the cross-sectional area of the flow path. The permeability of the DM establishes the permeability of the flow path.

The three distinct flow segments in any flow path (delivery, active area, and exhaust) are represented by the two manifolds, and the DM region above any disc. Ideally the manifolds have as much open space as possible, in order to minimize their required thickness in order to minimize the pressure drop across them. The radius of the discs, as well as the thickness and the permeability of the DM, must be optimized to

establish the desired pressure gradient, and overall pressure drop, of the active area segment, depending on the number of parallel paths over the active area.

The degree to which an even flow distribution over each parallel path is achieved is determined by the tolerances to which disc radius, DM thickness, and DM permeability can be held. The dimensional variations (radius and thickness) are most likely small compared with the variation in DM permeability, therefore DM permeability most likely determines how evenly flows become distributed. This assumes that a water removal condition where no liquid water is able to collect has been achieved.

Another unintended benefit: convective flow in the DM

An unintended benefit of this particular design is that by using the DM as the flow-interfering medium, an interdigitated-like flow field is created. An interdigitated-like flow field is beneficial because O_2 is carried through the DM by convection, rather than diffusion. The benefit of convection compared with diffusion is that mass transport losses are significantly lower for convective flow, compared with diffusive. Lower mass transport losses mean that O_2 partial pressure at the catalyst layer is higher than it would have been otherwise. This benefit is quantifiable in terms of a higher cell voltage.

Sh is a dimensionless parameter that compares the relative significance of gas transport by convection compared to diffusion for a system. The larger the value of Sh, the greater the significance of convective transport compared with diffusive transport. To determine the relative significance of these two mechanisms for a system, the following equation is used:

$$ Sh = \frac{convection}{diffusion} = \frac{h_m \delta}{D_{O_2}} = \frac{\Delta P_{O_2}^{diff}}{\Delta P_{O_2}^{conv}} $$

For the convective case, the distance (δ) starts from the middle of the DM layer instead of from the bottom of the layer as it does for the diffusive case. This causes δ to be half the value for convection that it is for diffusion. This gives an immediate 100% improvement in transport, just because the distance is shorter. Therefore Sh starts out at value of 2.

As would be expected, Sh is proportional to the drop in the P_{O_2} for diffusive transport compared with convective transport. This significance can be expressed in terms of voltage loss by using the equation:

$$ \frac{\Delta V^{conv}}{\Delta V^{diff}} = \frac{\ln\left(1 - \dfrac{\Delta P_{O_2}^{diff}}{Sh \cdot P_{O_2}^{FF}}\right)}{\ln\left(1 - \dfrac{\Delta P_{O_2}^{diff}}{P_{O_2}^{FF}}\right)} $$

As an example, at 1.0 A/cm^2 and fully humidified conditions, the reduction in the P_{O_2} over the thickness of a conventional sheet of DM would be ~90%.

$$ \frac{\Delta P_{O_2}^{diff}}{P_{O_2}^{FF}} = 0.9 $$

Comparing the relative voltage loss for this condition for each of the two transport cases, the loss for the convective case calculated in volts would be only ¼ what it would be for the diffusive case.

$$\frac{\Delta V^{conv}}{\Delta V^{diff}} = \frac{\ln\left(1 - \frac{0.9}{2}\right)}{\ln(1 - 0.9)} \approx \frac{1}{4}$$

A typical transport loss at this condition for diffusive transport is ~70 mV. For convective transport, this loss would be reduced to one fourth of that, or ~18 mV, for a savings of ~50mV.

In addition to performance improvements due to a reduction in mass transport losses of oxygen, the same principle applies to water vapor as well. Delivery of water vapor to the membrane would be improved due to the benefits of convective delivery, compared with diffusive. It is also hypothesized that there would be further benefits to convective flow, compared with diffusive, due to improved gas mixing.
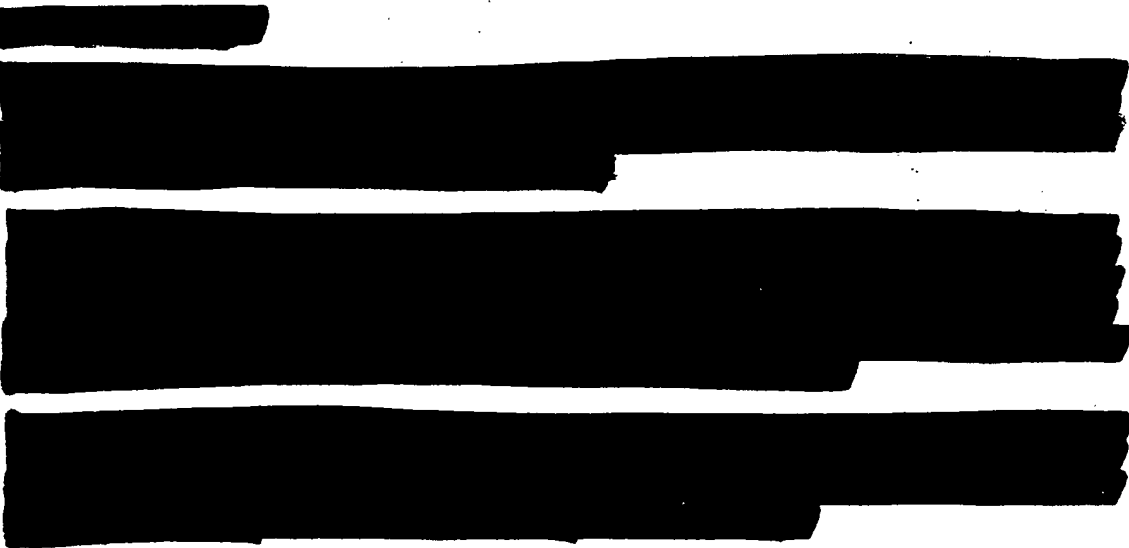
Actual construction

Construction of this flow field is accomplished using flex-circuit materials and fabrication techniques. A gas space can be created by first laminating a 0.010" thick sheet of stainless steel foil to a sheet of 0.002" thick polyimide. The stainless steel can then be patterned and etched to leave an array of 0.010" tall square or circular pillars. By making two of these and laminating them together, a gas space is created between the two polyimide sheets. The second gas space is created by putting the pillars that are not sandwiched between the polyimide up against the DM layer. For the metal-on-polyimide layer closer to the DM, there must be a set of empty vias in the center of each pillar (or disc) to form the tunnels that connect the bottom manifold to the DM. The final required feature is metal-filled vias in both polyimide sheets that line up with the stainless steel pillars in order to carry current across the entire thickness of the flow field.

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Page 16

Fig 3A
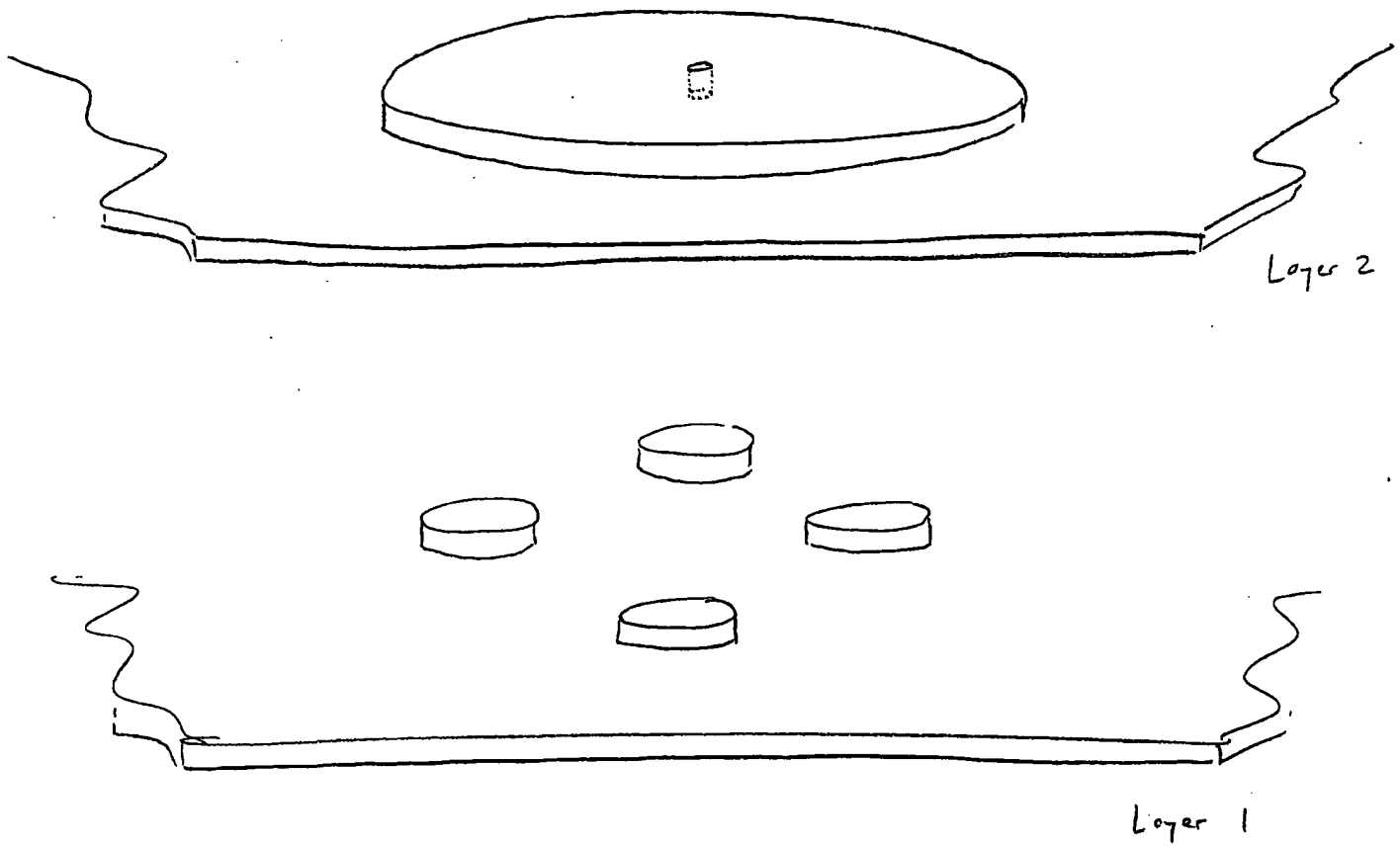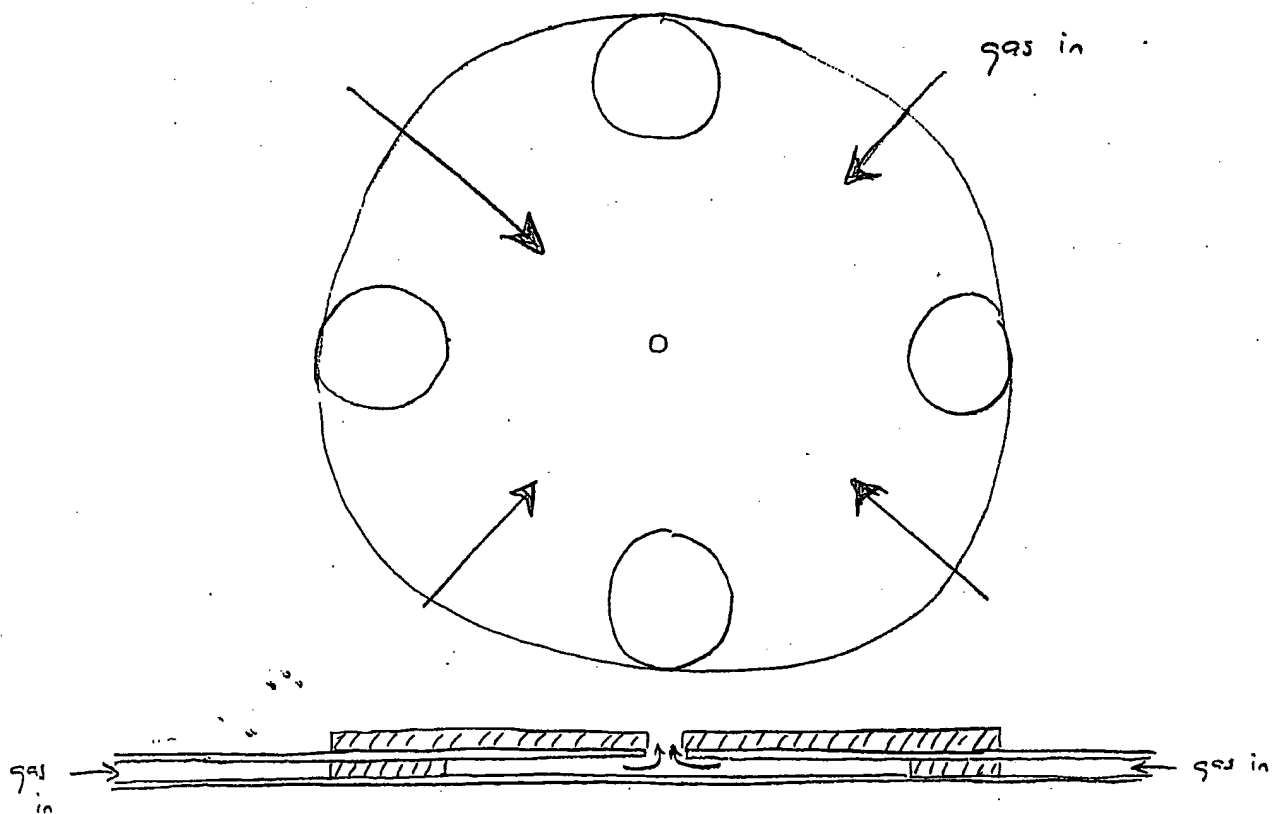
Layer 2

Layer 1

Fig 3B

gas in

O

gas
in

gas in

Layers 1 & 2

laminated together

(18)

Fig 3C

Flow field against DM

Gas flow occurs up through tunnel,
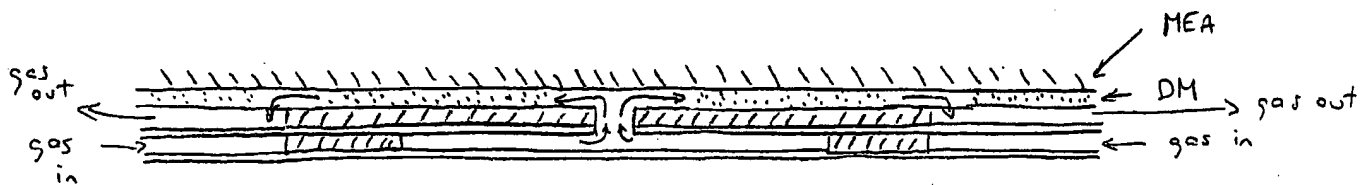through DM across the disc, down into
upper manifold

Fig 3D

Array of disks –

Active area is covered by array of discs